

Intersection of understanding: the digital, tactile and physical in fabric architecture

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ABSTRACT: The use of tensile fabric in architecture results in structures that can be both ecologically sensitive and delight the eye — but how do we begin to understand this non-traditional method of defining form and shaping space? Various methods of form finding help in understanding the capabilities of tensile fabric structures. Digital modeling, soap bubbles and stretchable fabrics can assist in understanding the inherent properties of fabric and the natural curvatures formed by the interaction of structure and fabric. These methods, however, are plagued by a steep learning curve and time investment that deters designers from utilizing fabric and makes it difficult to intuitively understand the properties of fabric. This paper explores how our group utilized a full-scale fabric installation meant to educate the user about the possibilities of fabric in architecture through an interactive and tactile experience. This study documented the users' initial knowledge and comfort level with fabric in architectural applications as well as their understanding of its material properties and compared this understanding to their understanding after interacting with the installation. The results of this study show how the use of a hybrid methodology of exploring a new material can lead to an increased understanding of how to utilize fabric for architectural applications and form finding.

KEYWORDS: Fabric Architecture, Form-finding, Computational Design, Experiential Learning

INTRODUCTION

From its earliest uses to contemporary applications, the use of fabric in architecture has resulted in delicate evocative forms that have delighted the senses of occupants. Despite a continued interest in thin lightweight structures throughout history, the specialty nature of the design, fabrication and construction of fabric structures has limited widespread implementation of this material type. The potential for enclosing large volumes of space with a minimal amount of material makes the use of tensile fabric in architecture increasingly relevant in this day and age of heightened interest in sustainable design principles (Bechthold 2008). In the Spring 2013 term, an intermediate design studio led by Assistant Professor Mark Donofrio in the Department of Architecture at the University of Oregon explored the potential of using tensile fabric architecture in environmentally sensitive locations. As part of the studio, students were charged with the design and construction of installations to be built around Lawrence Hall, the home of the School of Architecture and Allied Arts at the University of Oregon. The goal of these installations was to provide students with the hands-on experience of designing and constructing a tensile fabric structure with the intention that this experience would help inform design decisions to be made on the large scale projects. This paper outlines one group's approach of designing an installation which was intended to not only increase their own understanding of the potential of fabric in defining space in architecture, but also educate all those who interacted with the installation. Through this development of an interactive installation, the authors set out to expand the understanding of the potential of fabric in architecture beyond just the scope of those involved in the design studio.

1.0 FABRIC IN ARCHITECTURE

1.1. Historical developments

Fabric is one of the original materials used in architecture with its first known use dating back to more than 40,000 years ago. In the earliest known example of a manmade shelter, remains were found of animal skins draped over sticks at a site called Moldova 1 on the Siberian Steppe (Drew, 1979). Associated with nomadic tribes, the earliest tent structures were loosely woven fabric draped over a support framework. More permanent systems evolved over time, including shading systems for urban applications in hotter climates. Due to their lightweight and portable nature, tent structures proved useful for military functions, with leather tents being used by the Roman Legions in the 1st century B.C. (Faegre, 1979). Later, "novelty" structures

became popular in the twelfth century. These non-utility structures gradually became more ornate through the sixteenth century and were a sign of wealth and royalty. Beginning with the first travelling circus tents in the 1770's, fabric structures grew up to 50m in diameter. This burgeoning entertainment industry led to an increase in demand and the formation of tentmakers Stromeyer and Company.

In historic applications, these shelters were generally fabricated using traditional methods of handmade ropes and woven fabrics. The basic, generic forms of structure that were developed until this time still persist today due to their utility and function in particular applications. These original pure forms include the cone, hemisphere, cylinder, semi-cylinder, pyramid, and cube, as well as various combinations (Drew 1979). However, by the 1800's, advancements in rope strength and steel cables as well as suspension structures began to revolutionize long span bridge structures which in turn informed the structural elements of fabric architecture. By the 1950s Frei Otto began investigating the possibilities of this architecture and was supported by the aforementioned Stromeyer and Company tent manufacturers. Stromeyer and Otto collaborated for over 20 years and were instrumental in making pre-stressed fabric structures part of the modern architectural vocabulary (Otto, 2005).

1.2. Physical form finding

Physical modeling of tensile fabric structures seeks to recreate "the complex field of forces in equilibrium" which defines the form of fabric architecture (Berger 1998, 167). Experimenting with forming soap bubbles over proposed structural forms recreates this perfect equilibrium. This method can be used to create temporal forms over limited amount of structure. Frei Otto popularized the use of these studies at his Institute of Lightweight Structures at the University of Stuttgart (Bach et.al. 1988). Another method is draping and tightening elastic string over structure to create naturally curved forms meant to approximate the tension in fabric. The physical modeling method that is "most realistic in [its] structural behavior" utilizes stretchable fabric (Berger 1998, 168). This method is easily approachable, most accurate and results in a permanent model which can be further studied. These various methods of physical modeling have evolved to assist the designer in form finding as well as teach the designer about the properties inherent in tensile fabric structures.

1.3. Digital form finding

Computational modeling and analysis has expanded the realm of possibilities for fabric as a structural building material. What once was physically impossible or financially inconceivable with regards to fabric is now an accessible and desired reality. By utilizing complex algorithms and mathematical equations, computer models allow the user to make quick revisions as well as explore countless variations. This technology is much less time intensive and costly than a physical model approach. Physical modeling may continue to be useful for initial conceptual investigations, but final form finding, load analysis and patterning are now all undertaken using computers for reasons of speed and convenience (Koch et. al. 2004). What is most valuable about digital models for designers is the translation of relationships governed by physics into a visual representation. For example Kangaroo, a plugin for Rhinoceros3D parametric modeling plugin Grasshopper, enables geometric forms to be shaped by material properties and applied forces and interacted with in real time (Piker, 2013). While digitally modeling, the designer is aided by the software's extensive ability to simulate physical forces which frees them from a complete knowledge of physics. Instead the digital model allows changes to be made much more intuitively based on the other parameters the designer wishes to explore.

1.4. Need for a hybrid approach

While computational modeling is very strong in its ability to approximate the form of a structure being designed, it is less successful in communicating an intuitive understanding of the behavior and internal stresses of the material. Digital tools exist which can produce colored diagrams representing the stress distribution of a structure. While colored plots of structural forces are more useful to a designer than a table of pure numbers, without the proper background knowledge and understanding of how the software is working these tools can provide misleading and even incorrect results. Digital modeling has other disadvantages including the impossibility of capturing the visceral characteristics of fabric, such as the texture or the movement of the fabric with the changing winds. Some kinds of knowledge are only gained through the tactile hands-on experience of physical form finding. Additionally, computational modeling occurs in a closed box. There is much about the programming of these algorithms that is out of the control and expertise of the designer. Lastly, the level of proficiency in computational modeling exceeds the needs of most designers. One may master software for purposes of form finding, yet the collaboration of others will always be required to complete a detailed load analysis, patterning and construction. It is the designer's role to have a more general understanding of all the disciplines rather than a complete understanding of any one. Alternatively; hands on, physical models may be more beneficial in gaining the desired knowledge of fabric which would supplement digital methods.

2.0 INTERACTIVATED SPACES: INTERSECTION OF UNDERSTANDING



Figure 1: Photograph of Interactivated Spaces tensile fabric installation. (Source: Loeliger 2013).

2.1. Installation description

In order to explore the potential of full-scale form finding in synthesizing digital and physical methods, the authors conceived of an installation consisting of fabric panels suspended between connection points located on columns (Fig. 1). The installation takes advantage of four existing columns which create a breezeway between a quadrangle and the courtyard of Lawrence Hall. This is an area of moderate traffic and high visibility. Multiple fixed connection points were located on timber posts strapped to the four existing concrete columns located 17 feet apart in one direction and 28 feet apart in the other (Fig. 3). Eyebolts were placed at 8 inch increments on the timber posts allowing for a variety of support points that can be adjusted up or down by the user to change the forms created by the fabric. A sliding cable connection at the high point of the existing structure was connected to one corner of each fabric panel. Three fabric panels in total were permanently installed at the location; two of the panels had four corners while the third panel had three. Each corner of each fabric panel was equipped with a carabiner for attachment to the eyebolts (Fig. 2). The parameters of the installation were optimized to the location in order to provide for the largest range of formal possibilities and the desire to educate the user about how the relationship of connection points, adjustable variables, panel shape and size directly impact the form of a fabric structure.



Figure 2: Photographs of installation details: eyebolt connection, sliding cable connection and fabric panel corner.

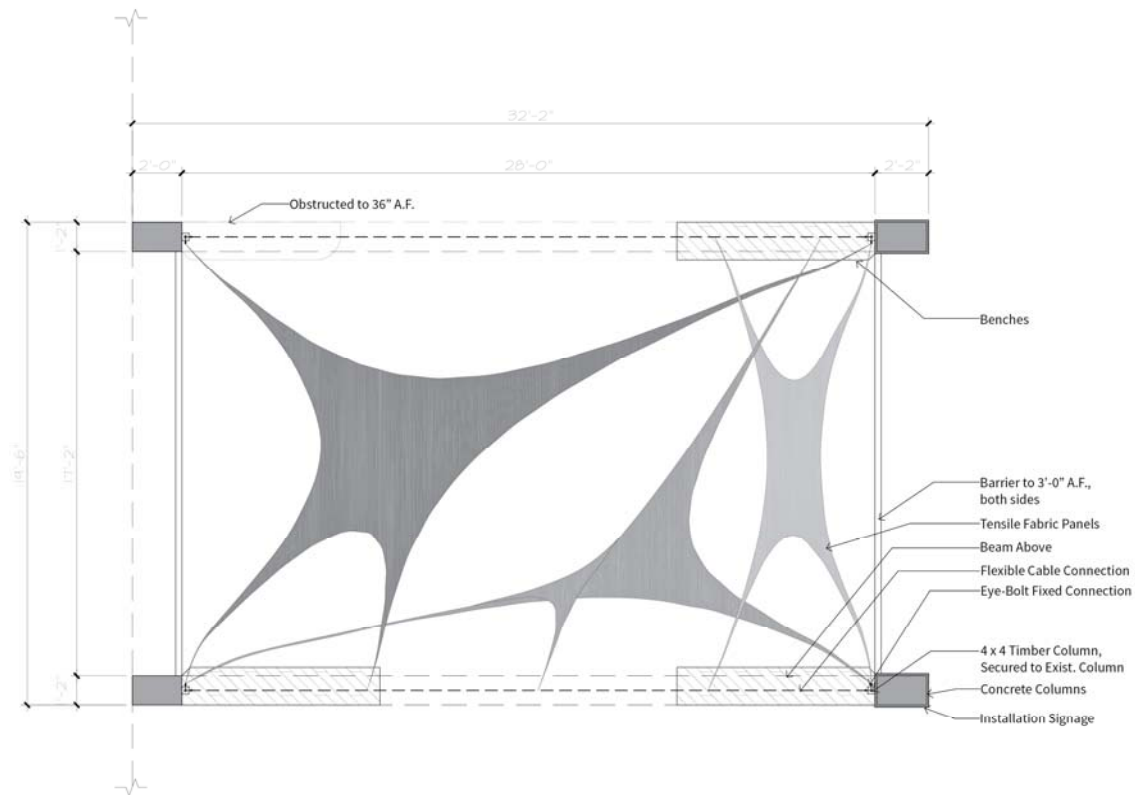


Figure 3: Drawing showing location of installation within existing breezeway columns.

2.2. Methodology

Our research consisted of two parts: applying methodologies used in defining the parameters of the installation as well as questionnaires answered by design students exploring their level of material understanding before and after interacting with the installation. During the first stage of research, we used techniques such as digital modeling in Rhinoceros3D software with the Grasshopper, Kangaroo and Weaverbird plug-ins as well as physical modeling, allowing us to establish the design parameters of the installation (Fig. 4). These techniques helped us establish ideal fabric shape, size, connection locations and test which variables should be adjustable by the user. Our time utilizing current methods of formal explorations gave us a thorough knowledge of the shortcoming of current methods and confirmed that a new method of understanding and teaching about fabric in architecture was required.



Figure 4: Physical and digital form-finding models utilized to optimize installation configuration and variables.

The second stage of our research utilized questionnaires which sought to establish the users initial knowledge of fabric and its material properties and their understanding once they had interacted with the installation. Our research pool consisted of 21 graduate and 35 undergraduate students engaged in the Bachelor of Architecture and Master of Architecture curriculums at the University of Oregon. These students served as our target audience as they are at once trained designers and curious about the use of new materials and forms in their designs. Before working with the installation, the students responded to a questionnaire asking how familiar they were with how fabric is used in the architectural profession and its material properties, formal capabilities and spatial characteristics. They also were asked how comfortable they were utilizing fabric in their architectural designs and how likely they were to do so. The students then engaged with the installation and documented their interaction through photographs of the form they created. Signage at the installation prompted the user to consider the material characteristics of fabric and its use in the architectural profession. The users were also encouraged to create a configuration with a specific spatial characteristic such as gathering, entrance or transition. After this interaction, the students were asked similar questions about the formal capabilities and possibilities of fabric, its material properties and the effectiveness of the design of the installation. The students were also asked the same qualitative questions about how comfortable they were using fabric in their designs and how likely they were to do so.

2.3. Process summary

The use of physical form finding models coupled with digital modeling led to an installation that utilized the benefits of each method while also attempting to eliminate the issues and limitations related to each. Our goal was the creation of an installation where designers would be able to focus on the formal possibilities of fabric architecture and not the technicalities of connection points, shape, patterning and be confined by the inherent limitations of different modeling methods. The intention was to devise a tool that bridged the gap between the limitations of small scale physical modeling and digital modeling to the understanding of a full-scale material application through the intuitive process of manually manipulating the material itself. This hybrid method was developed to educate potential users about how the relationship of connection points, adjustable variables, panel shape and size, etc. directly alters the form of a fabric structure through an intuitive tactile experience.

3.0. RESULTS

Analyzing questionnaires taken before and after interacting with the installation shows a general increase in the perceived usefulness of fabric to the architectural profession after utilizing the installation both in terms of form finding and for creating spatial qualities. While before questionnaires illustrated a generally timid use of fabric in temporary structures for shading or roof coverings; after utilizing the installation students saw the potential in using fabric to create permanent structures, for form finding and understood the formal and tensile properties of fabric.

3.1. Qualitative results

While before questionnaires established what existing experience and knowledge students had of fabric in architecture, comparing these to the after questionnaires illustrated what they had directly learned from the installation. Students exhibited a general knowledge of the material characteristics of fabric before interacting with the installation but lacked how to apply those methods to more substantial architectural applications. Typical existing knowledge of fabric utilized in architectural applications included use as awnings, partitions, shading, temporary structures and interior uses. Material characteristics of fabric that the students thought would be most beneficial to architectural applications before using the installation were that it is lightweight, can create adaptable forms and is flexible. After interacting with the installation, suggested uses for fabric tended towards more permanent and substantial architectural spaces such as stadiums, pavilions or public gathering spaces. Students also described material characteristics such as “tensile strength, physical flexibility and tactile qualities” after using the installation.¹ Specifically, before the installation a student would consider fabric for use in “sun shading and rain protection” while after using the installation the use of fabric had graduated to more formal architectural uses “to represent/define space”.² This reaction illustrates how the installation helped the user to internalize the important material characteristics of fabric through the tactile process of configuring the installation thereby allowing them to see more formal and structural possibilities for fabric.



Figure 5: Examples of various installation configurations realized by student users.

Fabric itself also took on a more primary role in defining space once the students had manipulated the installation. The architectural uses and material qualities of fabric discussed before the installation were most often ways to ornament a building or provide utilitarian shading. Once the students had experienced the installation, fabric was seen as a tensile and/or structural element that could define the form of the building itself and was talked about with more architectural and spatial vocabulary (Fig.5). A student representative of this trend felt like fabric “is typically used as an additional element to a structure rather than the primary structure” before using the installation. This perspective then shifted to fabrics’ use “as a primary element that can easily be reconfigured for varying uses” after the installation.³ Another student discussed how fabric “falls naturally” and could “be helpful in determining how loads are distributed” in non-rigid materials which are reliant on tension to create form.⁴

3.2. Quantitative results

The student questionnaires also included quantitative questions regarding the student’s comfort level using fabric and the likelihood of utilizing fabric in their own designs. The same questions were asked before and after interaction with the installation and were based on a scale from 1 to 5, with 1 being least comfortable and 5 conveying a high level of comfort. Comparing results before using the installation to after, 60% of students became more comfortable with using fabric. Among that percentage, 30% were not only more comfortable with fabric but were also more likely to utilize fabric in their designs (Fig. 6). These increases are attributed to their hands-on exploration with the installation. The tactile and intuitive nature of the installation provided them with an approachable and efficient learning tool.

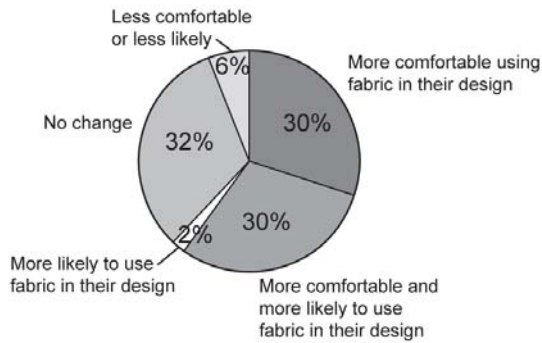


Figure 6: Percentage change in after response.

Answers to numerical questions varied between the undergraduate and graduate populations. Before interacting with the installation, graduate students were 12% more comfortable and more likely to use fabric in their designs. After the installation, the undergraduate students became 25% more comfortable and more likely to use fabric (Fig. 7). This shift possibly speaks to a differing willingness to utilize new materials and different learning styles related to age and life-experience levels. Results from the numerically based questions showed a significant increase in student comfort level and likelihood of using fabric. By eliminating the learning curve and limitations inherent in other form finding tools, the students were able to maximize the learning potential of their time with an installation that synthesized the positive aspects of the current methods.

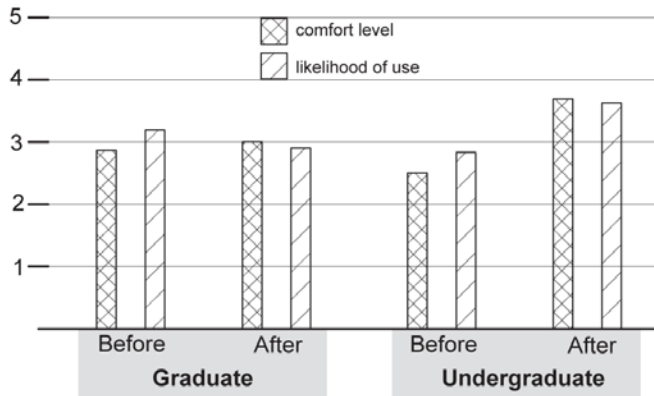


Figure 7: Average before and after survey responses.

CONCLUSION

The use of fabric in architecture has far reaching potentials, yet the specialty knowledge required for designing with fabric has limited its implementation and further development in contemporary architecture. The utilization of our hands-on installation informs an understanding and intuitive knowledge of fabric in architecture while also conveying the roots of knowledge necessary to design in fabric. It distills knowledge from both digital and physical modeling practices to create a new method of design communication that educates designers on the dynamic relationship of form, material, and structure. The installation removes barriers to understanding new formal possibilities in architecture by utilizing a material with tremendous capabilities and exploiting the curiosity of the user by making experimentation educational. This experimentation thereby provides the user with the opportunity to create new and interesting forms and relationships but also allows them the distinct opportunity to create non-tensile and less successful forms. It represents the need to remove barriers to learning by creating new methods of instruction which synthesize current methods but also create more approachable and efficient learning opportunities. Significant increases in the users comfort level and likelihood of using the material as well as the use of formal architectural language after utilizing the installation illustrates that it was successful in its educational goal.

The installation presents opportunities for further research into why undergraduate students became more likely to utilize a new material after experimenting with it while graduate students became less likely even while both groups show an increased understanding of the material. By creating an installation that was at once defined by the digital, refined through the tactile and experienced in the physical, we were able to create an experience that led to an increased understanding of the formal possibilities of fabric in architecture.

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ENDNOTES

¹ Questionnaire Survey response from M.Arch student Ally MacLean

² Questionnaire Survey response from B.Arch student William Page

³ Questionnaire Survey response from B.Arch student Nicole Ghiselli

⁴ Questionnaire Survey response from B.Arch student Joanna OConnell